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Commercial Production of Protein by the Fermentation of Acid and/Or Sweet Whey

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COMMERCIAL PRODUCTION OF PROTEIN BY THE FERMENTATION OF ACID AND/OR SWEET WHEY

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

"Commercial Production of Protein By the Fermentation of Acid/Or Sweet Whey" is a product of the above efforts. Currently the cheese industry in the United States is producing approximately 30 billion pounds of liquid whey annually. For each pound of cheese produced, approximately 9 pounds of whey is obtained. This report describes the commercial conversion of the lactose in whey into high quality protein via fermentation. The project shows how this conversion can be accomplished in a unique closed-loop system producing zero effluents. This process can utilize large amounts of whey and thereby convert this potential environmental contaminant to a useful product that can also be used in large amounts by the animal feed industry.

For further information regarding this report contact the Food and Wood Products Branch, Industrial Pollution Control Division, Industrial Environmental Research Laboratory--Ci, Cincinnati, Ohio 45268.

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ABSTRACT

Saccharomyces fragilis may be grown on acid or sweet cheese whey in a deep-tank, aerated fermentor in a continuous manner on a commercial scale. Operations in a 15,000-gallon fermentor at low pH and high cell counts experience no contamination during extended periods of time under sanitary but not sterile conditions. Media additions to the raw or diluted condensed whey include anhydrous ammonia, phosphoric acid, and yeast extract. The production of a condensed or dried whole fermented whey mass (yeast fermentation solubles), which is an acceptable high protein feed ingredient, eliminates additional processing of waste streams from yeast separators, increases fermentation yields, and utilizes the unfermented whey proteins originally present. Evaporation of the whole fermented whey mass produces condensate water that can be used to dilute incoming condensed whey and thereby operate a unique closed loop system with no effluents.

Economic calculations indicate that the process can be viable commercially, provided that a number of necessary conditions are met. First, large amounts of raw material (whey) must be available nearby at a low cost. Second, sufficient capital investment must be made to build a highly automated and controlled plant so that labor costs are minimized. And third, the operation and process should be versatile enough to change product mix (e.g. to food grade yeast, ethanol production, new products, etc.) if future energy or market considerations warrant it.

This project shows that the commercial fermentation of cheese whey is another means of converting large amounts of a potential environmental pollutant into useful and needed products.

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SECTION I

INTRODUCTION

Currently the cheese industry in the United States is producing approximately 30 billion pounds of liquid whey annually. As recently as 1972, it was estimated that only about half of the whey produced was utilized.[1] For each pound of cheese produced, approximately 9 pounds of whey is obtained. In 1975, the last year for which statistics are available, 820 million pounds of dry whey was produced (625 million pounds for human consumption 195 million pounds for animal feeds).[2] Other amounts of whey were converted to lactose, whey blends, protein fractions, etc. But if it is recognized that the 30 billion pounds of whey previously mentioned represents about 2 billion pounds of whey solids, it is easily seen that a tremendous amount of this material is being discarded.

Whey is the serum of milk resulting from the removal of fat and casein from the whole milk during the cheese-making process. It is a greenish-yellow liquid containing 6% to 6.5% solids and most of the water soluble vitamins and minerals of the whole milk from which it was derived. A typical analysis of the whey solids would be: lactose 64% to 72%, protein 11% to 13%, minerals 8% to 9%, plus small amounts of fat and lactic acid. Practically all the whey produced in this country is of two types: low acid (sweet whey) from cheddar, Swiss or Italian cheeses, and high acid (acid whey) from cottage or cream cheese.

The problem of disposing of or utilizing whey is compounded by a number of factors. The material is 93.5% to 94% water, which makes hauling any distance extremely expensive. It is perishable and will spoil easily, so it cannot be stored for any length of time. Evaporation and drying of whey requires a large capital investment, and the market for dried whey is such that often the cost of processing is just barely recovered. Also, acid whey is extremely difficult to dry at all, and it can only be done with specialized equipment. Such processing may nevertheless be cheaper than trying to

disposal of the liquid. The BOD of raw whey is about 30,000 to 50,000 ppm, and since it is not unusual for a cheese plant to produce 500,000 to 1,000,000 pounds of whey per day, it would require a large disposal or treatment plant to handle this volume.

One of the few industries capable of utilizing the large volumes of whey available is the animal feed industry. Unfortunately, the price that can be paid for dried whey for feeding purposes is low, often just about equal to the processing costs. The reason is that the major constituent of dried whey is lactose, which can be used only in limited amounts in most feeds and must compete in price with other inexpensive carbohydrate and energy sources such as molasses and corn. There is a much greater demand for high-protein ingredients in this area.

This report describes the commercial conversion of the lactose in whey into high quality protein via fermentation. The project shows how this conversion can be accomplished in a unique closed-loop system producing zero effluents. This process can utilize large amounts of whey and thereby convert this potential environmental contaminant to a useful product that can also be used in large amounts by the animal feed industry.

SECTION II

CONCLUSIONS AND RECOMMENDATIONS

1. Saccharomycopsis fragilis can be grown on acid or sweet whey in a deep-tank, aerated fermentor in a continuous manner on a commercial scale.

2. Growth levels of several billion cells per milliliter were reached and maintained for up to 2 weeks of time without any contamination while operating a 15,000-gallon fermentor under sanitary, but not sterile conditions.

3. The entire fermented whey mass may be condensed and/or dried to produce an acceptable and satisfactory high-protein (35% to 50%) feed ingredient (yeast fermentation solubles, YFS). The yield of such YFS material is between 0.65 and 0.75 pounds per pound of whey solids.

4. The evaporation of the whole fermented whey mass eliminates additional processing of waste streams, increases fermentation yields, utilizes unfermented whey proteins present in the media, and produces condensate water that can be used to dilute incoming condensed whey. This allows the fermentation to be operated in a unique closed-loop system producing zero effluents.

5. A superior quality yeast, higher in protein (45% to 55%) and lower in ash (6% to 10%) content, may be produced by centrifugal harvesting of the yeast cells. This product will find commercial applications as a food additive for its nutritional and flavor characteristics.

6. Supernatant effluents from yeast separators may be incorporated into the YFS feed material and thus utilize the soluble, unfermented whey proteins that would otherwise be lost.

7. By changing the conditions of the fermentation, up to 9% ethyl alcohol may be produced which can be recovered during the evaporation stage.

8. The process is commercially viable, provided large amounts of low or no-cost whey are available and the production is sufficiently automated and controlled to minimize labor costs.

9. Further studies should investigate making the process versatile enough to vary the product mix to meet cost and market fluctuations. Special emphasis of future work should include study of the optimal production of ethanol as a possible alternate fuel source.

SECTION III

MATERIALS AND METHODS

Since the work reported here is a continuation of extended preliminary and pilot experiments reported elsewhere,[1] the materials and analytical methods remained the same. Minor variations in procedures were experienced in the scale-up from a 500-gallon operation to working in a 15,000-gallon fermentor. For example, anhydrous ammonia was used as the exogenous nitrogen source instead of aqueous ammonium hydroxide to avoid medium dilution because of large volumes, to decrease operating costs, and to enhance automatic pH control.

Incoming condensed whey (either acid and/or sweet) was diluted to the appropriate lactose concentration (equivalent to 10% to 15% whey solids) with water, raw whey or condensate water as described in the process section. Other additions included, phosphoric acid, yeast extract, anyhdrous ammonia, and hydrochloric acid to give a typical medium composition as follows:

Whey solids	12.0%
Phosphoric Acid	0.1%
Yeast Extract (Amber BYF Series 100)	0.13%
Ammonia	0.3% to 0.5%
Hydrochloric Acid	0.5% to .0.2% (to pH 4.5)

The organism used was Saccharomyces fragilis (N.U.R.L., Y-1109). Inoculum buildup was accomplished as reported previously from stock slant to shake-flasks to 10 liters in a 14-liter fermentor to 60 gallons and to 300 gallons in a 500-gallon seed fermentor. When growth reached a minimum of

1 x 10^9 viable cells/ml, this seed was used to inoculate first 1,000 gallons and then 10,000 gallons of medium in the 15,000-gallon production tank. The progress of the fermentation was followed by lactose concentration, cell count and cell pack volume.

Analyses were made on samples of all fractions obtained during the fermentations, especially effluents (see Section V and tabulated results). These varied from 4 to 12 in number, depending on the degree of processing of the fermentation broth and included such tests as Kjeldahl nitrogen, ammonia nitrogen, lactose, ash, protein, pH, temperature, solids (or moisture), BOD, suspended solids, and ethanol.[3] Since the vast majority of the final series of fermentations were run using the closed-loop system producing no effluents, the number of monitoring points were eventually reduced to 6 in number.

SECTION IV

PROCESS

The fermentation of whey by various microorganisms has been known and studied for years.[4,5] Our own preliminary work, reported elsewhere,[3,6] showed that the organism of choice in our process is a strain of Saccharomyces fragilis. The conversion of lactose into cellular material is efficient and in the range of 45% to 52% under nonsterile conditions. Successive scale-up has been accomplished from shake-flasks to 14-liter fermenters to 500-gallon and 1,000-gallon fermenters to our present operation in a 15,000-gallon tank.

Whey (acid and/or sweet) is obtained in concentrated form (45% to 50% solids) from cheese manufacturers. This is diluted with water, raw whey or condensate water (as in "closed-loop" operations, to be described shortly) to the appropriate lactose concentration. Other medium additions include: anhydrous ammonia as the primary exogenous nitrogen source, yeast extract, phosphoric acid and some hydrochloric acid to adjust the pH to 4.5. The medium is heated to 80° for 45 minutes and then cooled. The fermentation is carried out in a 15,000 gallon stainless steel deep-tank fermenter that is fully aerated and jacketed. Automatic instrumentation controls pH (4.5), temperature (90-92°F), aeration (1.0 ± 0.2 vol. air per vol. medium) and foaming, as well as levels and volumes in and out. The fermentor may be operated in a batch, semi-continuous or continuous manner. After fermentation, the fermented whey mass is collected and processed further. An overall schematic of the fermentation process may be seen in Figure 1.

In a batch fermentation, starting with a seed with a viable cell count of 1 x 10^9 cells per milliter and an inoculum level of 10%, all the lactose is utilized in 8 hours under appropriate conditions with an increase in cell concentration of ten to twenty fold. This represents a generation time of approximately 2.0 hours and 4 doublings within an 8 hour period.

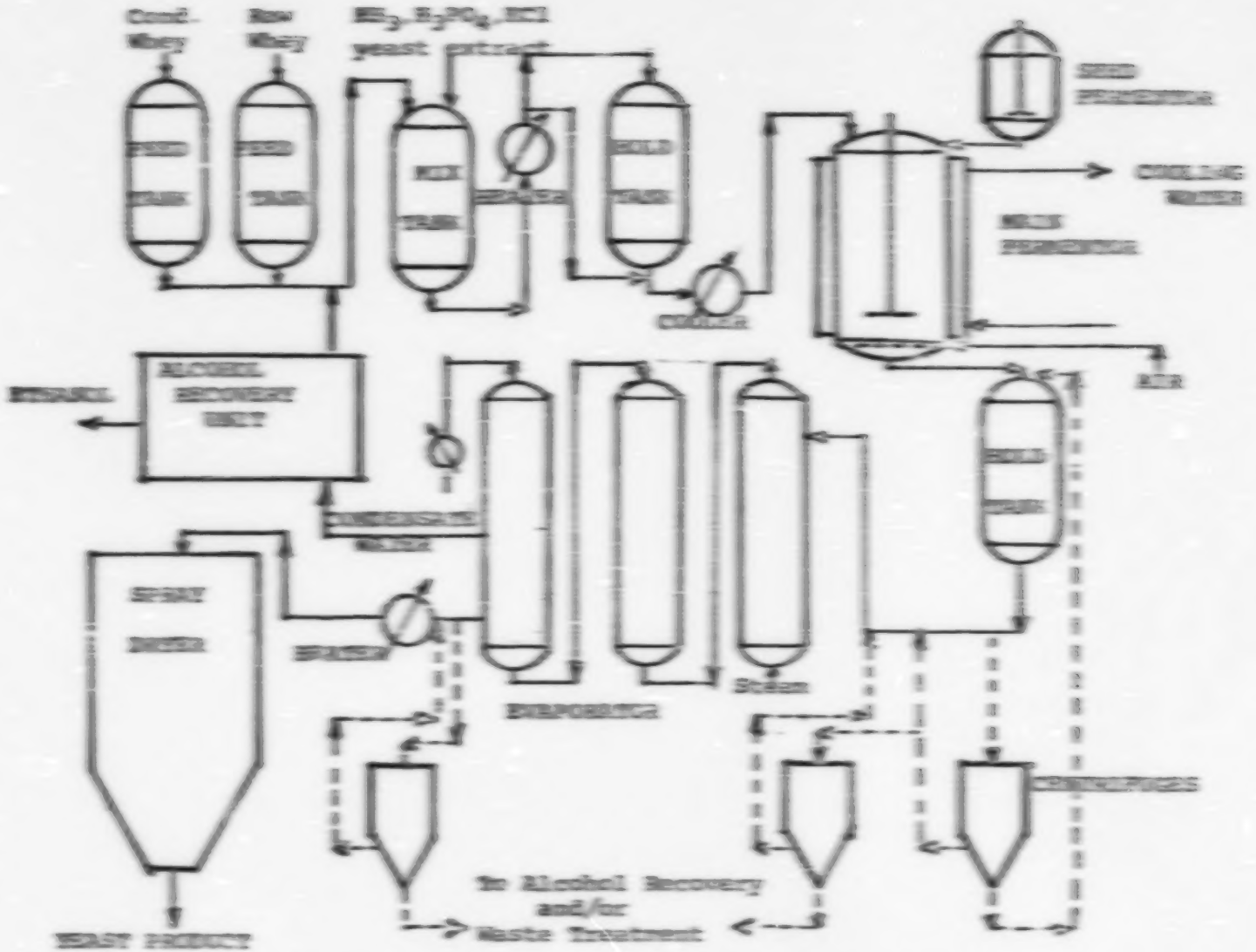

Figure 1 Schematic for Whey Fermentation Process

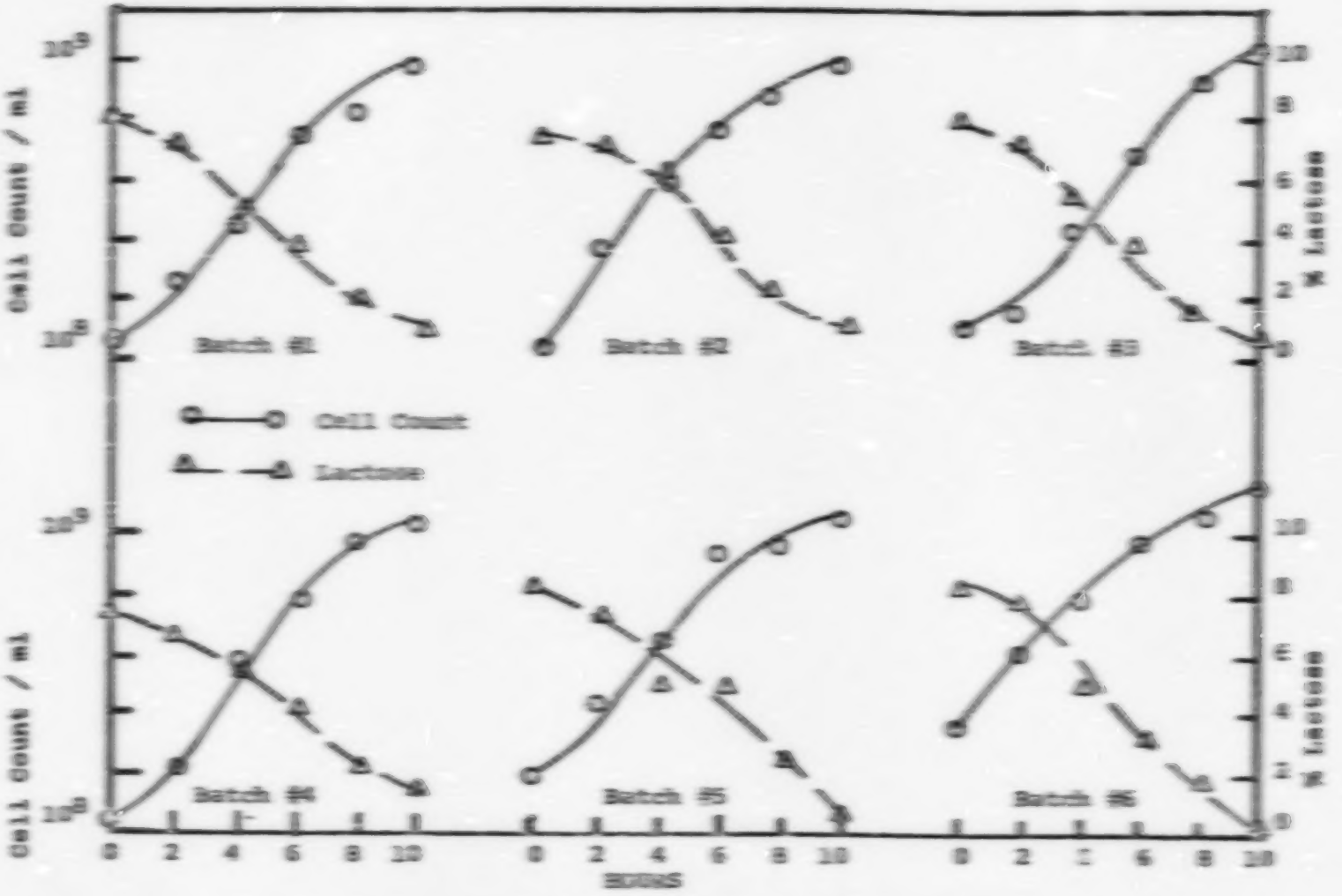

Figure 2 Semi-continuous Fermentation

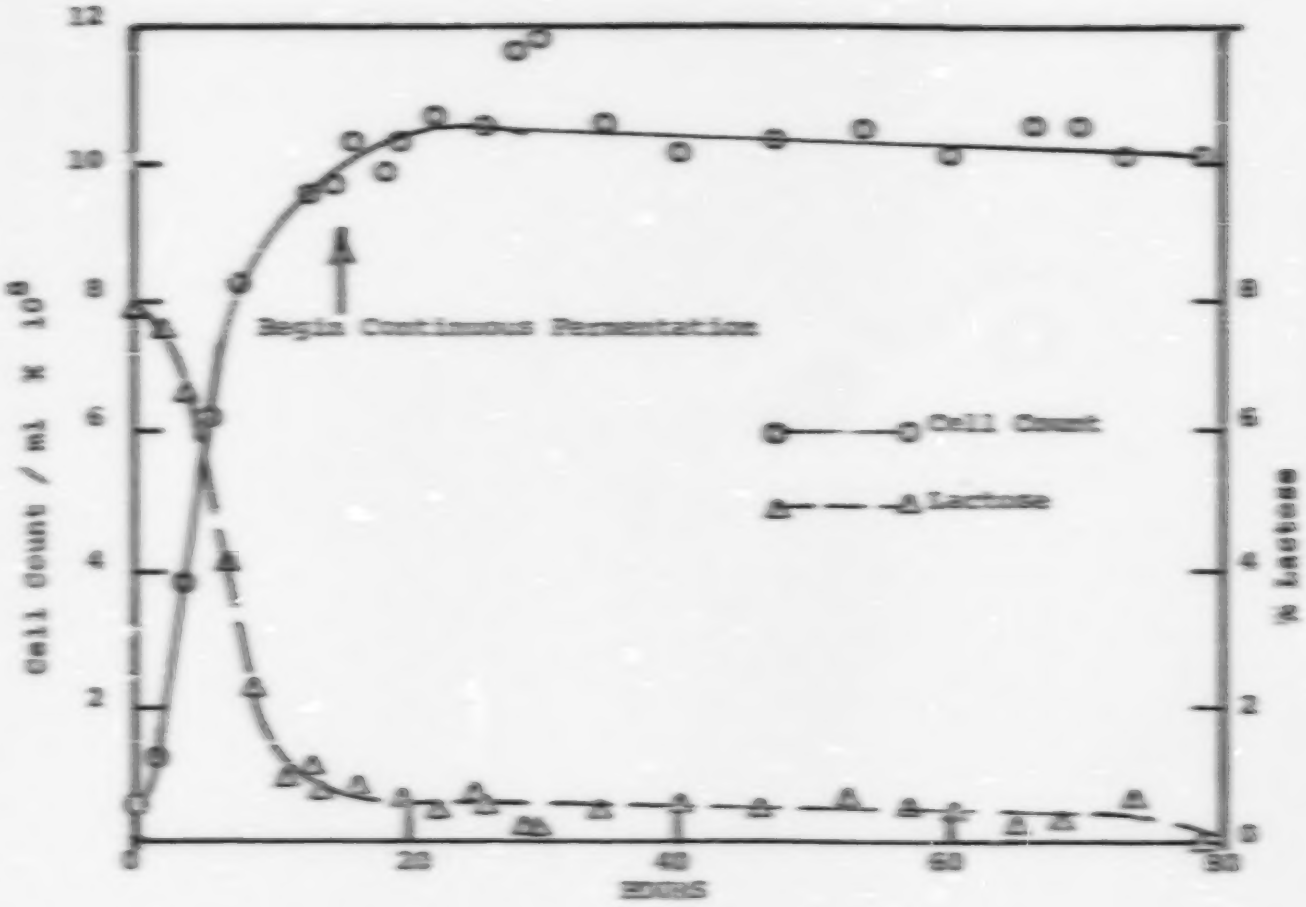

Figure 3 Continuous Fermentation in 15,000-gallon fermentor

The semi-continuous runs were made by drawing off 90% of the fermentation broth and using the 10% remaining to seed the next fermentation batch. A number of consecutive draw down batches could be run in this manner (Figure 2). The only "down-time" experienced in such a procedure is the time it takes to pump off 90% of the fermented broth and to pump in fresh medium.

The "down-time" can be eliminated if the fermentation can be run continuously, i.e., with the continuous addition of fresh medium and the removal of the fermented mass. This proved to be applicable in our yeast-whey fermentation. The continuous fermentation is begun when the cell count in the fermentation broth reaches 1 x 10^9 cells per milliliter and the lactose concentration falls to 0.50% to 0.75% (W/V). At this time fresh medium is added and the fermented whey mass removed at an equal rate. The fermentor may be operated in this manner for up to two-three weeks of time, maintaining both cell count and lactose concentration at a relatively constant level, without any indication of contamination or build-up of metabolic products that would interfere with the fermentation. In the 500 gallon and 3000 gallon tanks, continuous runs of several weeks have been accomplished. The 15,000-gallon fermentor has been operated in this manner for up to 15 days with no difficulty. One such run in the large tank is shown in Figure 3. After initial cell growth, fresh medium is added and the fermented whey mass removed at the rate of 1,250 gallons per hour, which corresponds to a batch fermentation cycle of 10,000 gallons per 8 hours (dilution rate of 0.125 hours $^{-1}$).

The production of Saccharomyces fragilis on whey has been done in the United States on a small scale [7] and is approved for use in feeds and foods.[8] The whole fermented whey mass (called AMBER Yeast Fermentation Solubles, YFS) can be used as feed ingredient. This simplifies the processing for it entails only the concentration of the fermentation broth and spray drying. If the yeast cells are harvested by centrifugation and washed, a food grade, primary grown yeast is obtained (AMBER Nutrex). The proximate analysis of these products are shown in Table 1.

TABLE 1.
PROXIMATE ANALYSIS OF
FERMENTED WHEY PRODUCTS

Constituent	Yeast Ferm. Sol. Amber YFS (%)	Cent. Yeast Amber Nutrex(%)
Crude protein	35-50	45-55
Ash	12-20	6-10
Fat	2-3	2
Moisture	3-4	3-4

The use of these products as feeds or foods and the quality of the protein they contain are indicated by rat feeding tests. Rat growth rates using YFS and centrifuged YFS as the sole protein source in the diet were compared with those using casein standard. No evidence of toxicity was noted during this period of time. From these experiments, Protein Efficiency Ratios (PER) were calculated and found to be 1.72 for the whole Yeast Fermentation Solubles and 2.26 for the centrifuged yeast[9] (Table 2). These values are 69% and 91% respectively of that of the casein standard. Actual feeding tests conducted with larger animals determine specific values. Such tests with cattle have proved successful and the YFS material is being used in a number of commercial feed formulations at the present time.

TABLE 2.
PROTEIN EFFICIENCY RATION (PER)
ASSAYS OF FERMENTED WHEY PRODUCTS

PRODUCT	Average per Value for 4 Weeks	% of ANRC Casein
Amber YFS	1.72	69
Amber Nutrex	2.26	91
ANRC Casein	2.50	100

The quality of the protein produced by this fermentation of whey is further indicated by the amino acid analysis. In Table 1 the amino acid composition of this yeast is compared to other yeasts used in feeds and foods (Brewers Yeast and Torula Yeast) and to yeast produced by the fermentation of hydrocarbons and ethanol. The standard amino acid FAO profile is also listed for comparison.

During the fermentation, one of the metabolic products formed is ethyl alcohol. By changing conditions of fermentation (operating under anaerobic conditions, 0.1 to 0.3 volume of air per volume of medium) one can increase the amount of this material formed. The results of one such run in our 15,000-gallon fermentor is shown in Figure 4. After an initial period of aerobic operation to build up cell concentration, the fermentation broth was "spiked" with additional lactose in the form of condensed whey and the fermentor was run under anaerobic conditions. The lactose was utilized at a continuous steady rate. The cell population no longer increased, but remained at a constant level. By adding condensed whey incrementally, ethyl alcohol was produced in larger amounts, and better than 90% of the lactose was converted to this material, the rest being metabolized for cell maintenance. The production of over 9% ethanol in this preliminary experiment indicates the potential of the production of this important chemical, simultaneous with the production of single cell protein. Complicated economic factors, including energy, production and recovery costs, as well as market values of the products, will determine the optimum operation of the process.

In an effort to minimize waste streams from the fermentation operation, a "closed-loop" system was designed. In this process the concentrated whey was diluted with condensate water derived from the evaporation of the fermentation broths, and this was followed by the fermentation of the whey. Theoretically, this closed-loop could be repeated as often as new whey was added to the cycle (Figure 5).

TABLE 3. AMINO ACID CONTENT OF VARIOUS SINGLE-CELL PROTEINS COMPARED TO FAO PROFILE

AMINO ACID	FAO profile	% of total protein: Amber Nutrex	Brewers yeast	Torula yeast	Brit. Pet.[10] yeast	Amoco[11] yeast
Lysine	4.2	6.9	6.8	8.5	7.5	6.6
Methionine	2.2	1.6	1.5	1.5	1.8	1.4
Valine	4.2	5.4	4.7	5.6	5.8	5.7
Leucine	4.8	7.0	5.8	8.0	7.8	7.1
Isoleucine	4.2	4.0	3.6	6.4	5.3	4.5
Tyrosine	2.8	2.5	2.7	4.3	3.6	3.3
Phenylalanine	2.8	3.4	3.4	5.1	4.3	4.1
Tryptophan	1.4	1.4	1.1	—	1.4	1.2
Histidine	—	2.1	2.1	2.2	2.1	2.1
Threonine	2.8	5.8	5.8	5.1	4.4	5.5

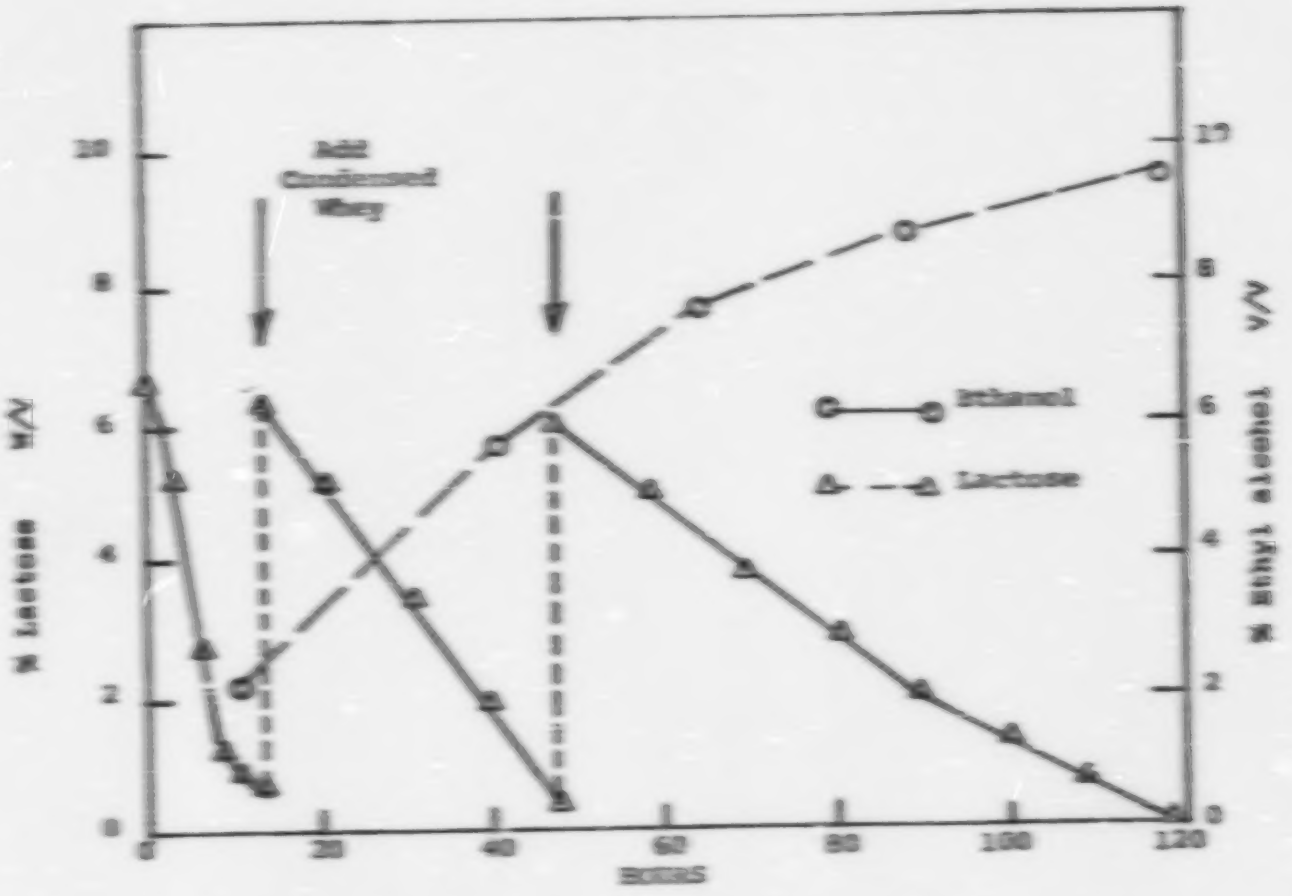

Figure 4 Ethanol production by anaerobic fermentation

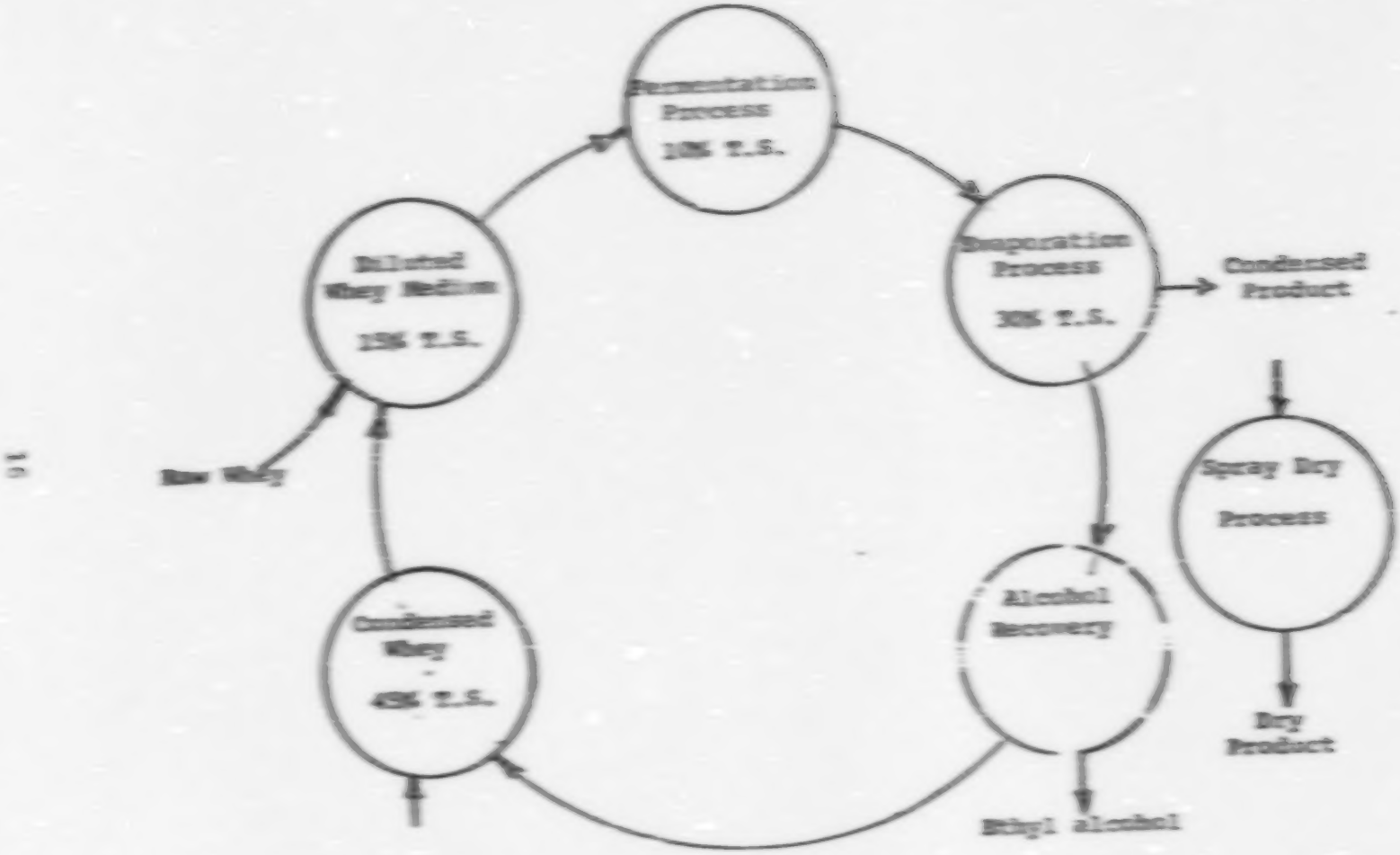

Figure 5 Closed-loop system for fermentation with zero effluents

Since the entire fermentation broth is spray dried, no waste streams are obtained. Effectively, therefore, this process has zero effluents. The fermentation results do not differ significantly whether tap water, raw whey or condensate water is used to dilute the incoming condensed whey. The process has been run over extended period of time, using this closed-loop system, with no apparent build-up of any metabolic toxic product to inhibit the fermentation. In the overall schematic shown in Figure 1, one can see the return of the condensate water to the medium mixing tank.

SECTION V

ANALYSES AND CHARACTERIZATION OF PROCESS STREAMS

The results of fermentation of whey by S. fragilis are reported in the Process section where they pertain to cellular growth and product characterization and use. Additional tests were run to monitor and characterize the various streams and fractions produced. These are summarized in Table 4 and represent a summary of the range of analyses obtained over many months of operation and many fermentations run in various ways. Samples were taken during the fermentations at a number of monitoring points in the process (Points A - L, Figure 6) (also, see Methods and Materials).

Condensed whey (either acid or sweet) had initial BOD values from 350,000 to 800,000 mg/l compared to those of raw whey, which were in the 37,000 to 50,000 mg/l range.

If the fermentation was run to produce YFS material, the whole fermented whey mass was evaporated and spray dried. Evaporator condensate contained some ethyl alcohol. If possible, this alcohol should be recovered by stripping in a distillation column. The condensate, with or without the alcohol removed, can be recycled and used to dilute incoming condensed whey.

If the yeast cells are harvested for food grade material, additional fractions from the centrifuges are obtained. The first supernatants have a high BOD (60,000 to 104,000 mg/l) because of the ethanol and soluble protein and other organic material they contain. This stream may be added to raw YFS material before evaporation and thus recover these constituents. The final supernatants (washings) contain such low levels of soluble materials (0.5% to 1.8%) that it may not be economical to recover them in this manner. In such a case, the final streams (containing BOD of 10,000 to 20,000 mg/l) would have to go to some further form of waste treatment.

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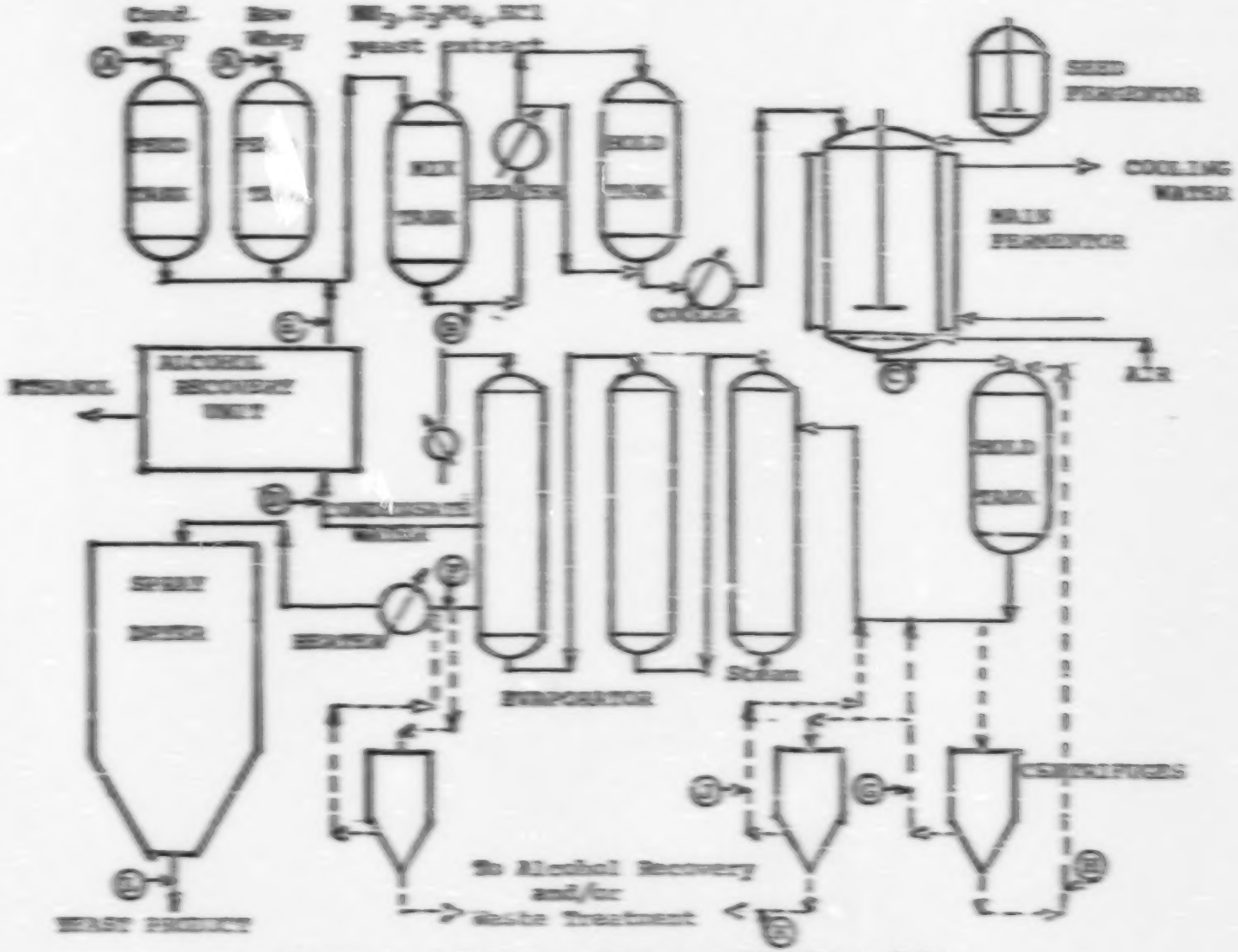
SEED FERMENTOR
COOLING WATER
MAIN FERMENTOR
COOLER
ALCOHOL RECOVERY UNIT
PENICILLIN
AIR
SEED TANK
SEED TANK
SEED TANK

SECTION VI

PRODUCTION OPERATION AND MATERIAL BALANCE

The demonstration plant was operated as described in the PROCESS SECTION (IV) for a continuous period of six to eight months. During this time, standard operations included using fresh seed each week, inoculum build-up, cell build-up and continuous fermentation for 72 hours. During each 24 hours of continuous fermentation, the material balance is indicated in Figure 7 and the Total Mass Balance and Water Balance in Tables 5 and 6, respectively. Operation in this manner was at an annual production rate of 2000 tons of feed material (YFS) and represented the use of approximately 100,000,000 pounds of raw whey equivalent as raw material. This level of production is 50% to 60% of the actual plant capacity and was dictated by sales and new market development and customer testing. In addition, during this period of time, over 100 tons of food grade yeast (Nutrex) was produced for customer evaluation.

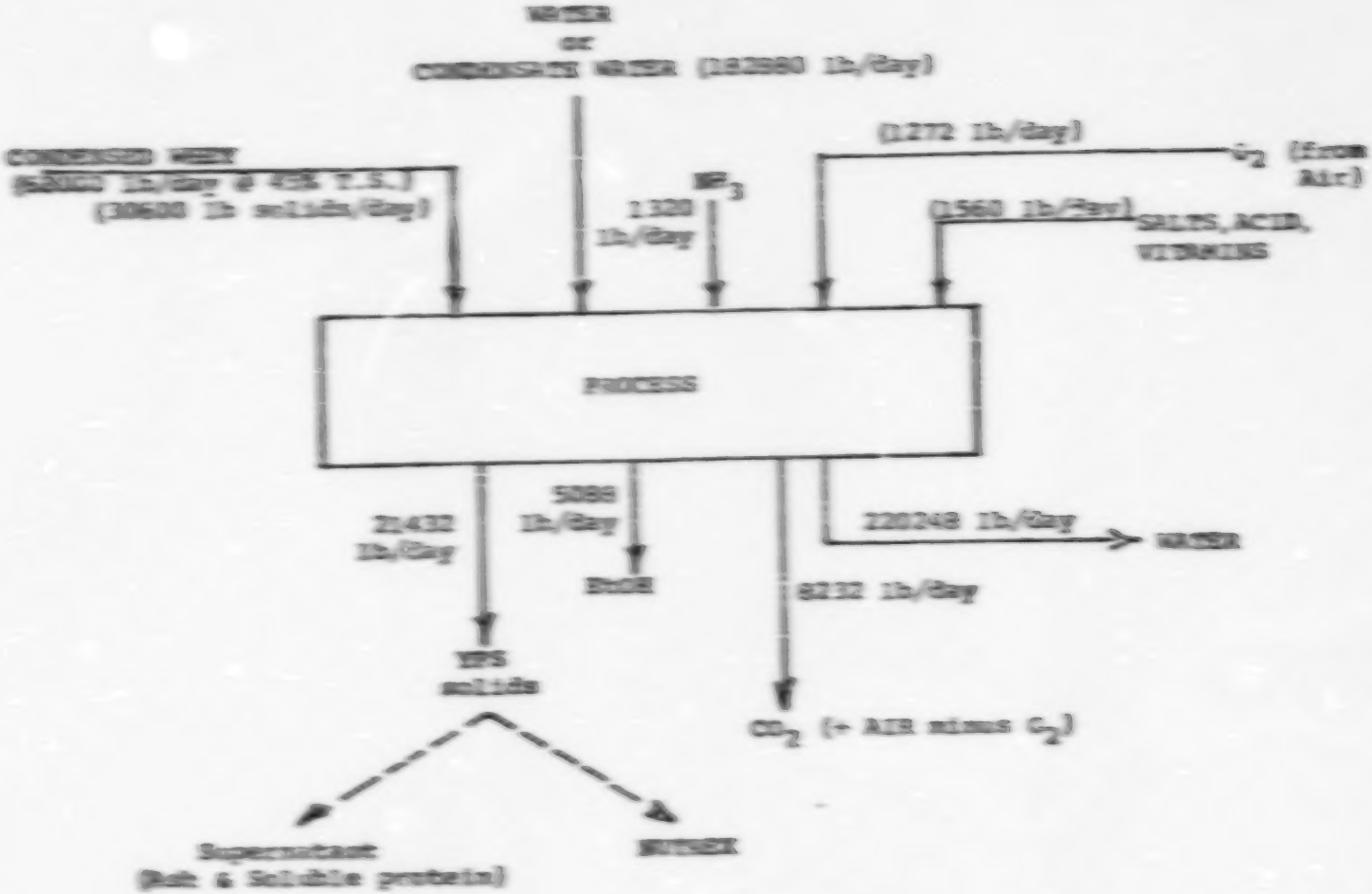

Figure 7 Material balance for whey fermentation

TABLE 5. TOTAL MASS BALANCE

Material	Amount (lb/day)
Input material:	
Whey solids*	10,600
Water*	220,248
Salts, acid, vitamins	1,560
Ammonia (NH_3)	1,320
O_2 from air	1,272
Total	255,000
Output material:	
YFS solids	21,432
water	220,248
Ethyl alcohol (EtOH)	5,088
CO_2	8,232
Total	255,000

*Source of whey solids and water is either 39,864 lb condensed whey + 210,984 lb raw whey or 68,000 lb condensed whey + 182,848 lb water.

TABLE 6. WATER BALANCE

Material	Amount (lb/day)
Input water:	
From:	
39,894 lb condensed whey	21,936
+	
210,984 lb raw whey	198,312
Total	220,248
or	
From:	
68,000 lb condensed whey	37,400
+	
182,848 lb water or condensate water	182,848
Total	220,248
Output water:	
From:	
Evaporation of YFS (fermentation broth)	170,240
Drying	50,008
Total	220,248

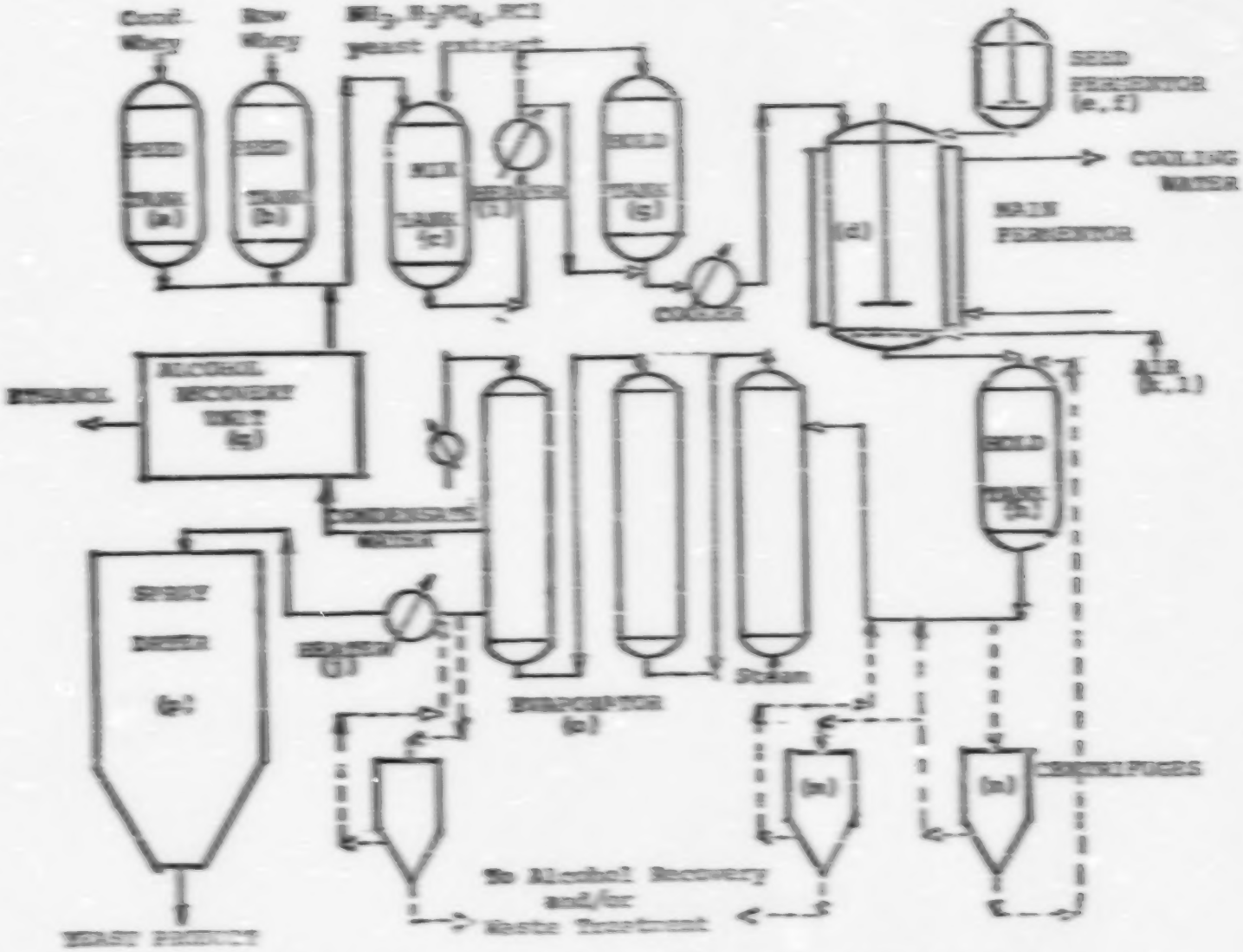

Figure 8 Schematic for Whey Fermentation Process

SECTION VII

EQUIPMENT DESCRIPTION

All equipment used throughout the plant is stainless steel (304 or 316), and all piping and fittings are sanitary design and in most instances tanks and lines are connected to CIP systems for cleaning. Major pieces of equipment are described below and may be identified in Figure 6. Not included are necessary support equipment such as pumps, mixers, acid and anhydrous ammonia storage, intake areas, product packaging and storage, utilities, etc.

Identification	and description	Size
a,b	Feed tanks (2)=========each=======	20,000 gal.
c	Medium mix tank==================	15,000 gal.
e,h	Hold tanks (2)=========each=======	30,000 gal.
d	Main fermentor===================	15,000 gal.
e	Seed fermentor===================	500 gal.
f	Seed fermentor===================	1,000 gal.
i	Plate (heater/cooler)============	1,000 GPH
j	Plate (heater)===================	2,000 GPH
k,l	Air compressors, (2) each======== reciprocating	1,300 CFM at 60 psi
m,n	Yeast Centrifuges, (2) continuous, nozzle type--each--	10,000 GPH
o	Evaporator, triple effect, vacuum	30,000 lb water/hr

p	Spray dryer	1,500 lb product/hr
q	Alcohol recovery unit including: distillation column (3' diam., 29 bubble cap trays) distillation column (20' diam., 15 bubble cap trays), Condensers (2) (420 sq. ft. and 360 sq. ft.), reboilers, pumps, 9 tanks, piping, fittings, etc.----------	500,000 gal/yr

SECTION VIII

ECONOMICS

Cost calculations of the large scale fermentation confirm those projected in the extended pilot fermentor operations[3]. The cost of the medium for the fermentation is primarily determined by the cost of whey. While it is possible in the future this material may have a negative cost due to the necessary costs of waste treatment of pollution abatement, at the present time, it is realistic that whey may be obtained at no cost or for the cost of evaporation and/or transportation alone. The actual costs ranged from zero to one cent per pound whey solids delivered for raw whey and one to four cents per pound whey solids delivered for condensed whey. The medium cost is 0 to 4.5 cents per pound of finished product.

The cost of production is also affected by the size of the operation. Labor and other costs decrease on a per pound, finished product basis as the size of the equipment and its degree of automation and sophistication increases. However, as the capacity increases so does the capital investment with its connected charges for depreciation, taxes, insurance and physical facilities. A plant capable of an annual production of 5,000 to 10,000 tons per year would cost in the range of $6 to $15 million, depending on its design, and this is still considered a small fermentation plant. Those being designed for the production of single cell protein from hydrocarbons are in the 100,000-ton annual capacity range. Calculations using present labor, utility and capital investment figures indicate that the feed grade material can be produced in a plant with an annual capacity of 5,000 to 10,000 tons for a total production cost of 11.6 to 16 cents per pound. This does not take into account any credit for alcohol recovered which can be of the order of several cents per pound, depending on the conditions of the fermentation and the yields obtained. The process looks economically viable at present. Its future viability will depend on market conditions and availability and cost of energy and expansion dollars.

TABLE 7.
CALCULATED PRODUCTION COST FOR DRIED YEAST FERMENTATION SOLUBLES FROM WHEY FERMENTATION (1974-1975)

Item	¢/lb. of product
Medium	0 - 4.5
Operating utilities:	
Evaporation and drying	1.45
Aeration, cooling	1.00
Other	.40
Labor	2.40
Capital investment	2.05 - 4.0
Overhead	2.40
Total	11.8 - 16.15

During the time of this study the actual production cost averaged to 15.4 cents/lb. of YFS material produced. Sales of this material were made at 18¢ to 24¢/lb.

SECTION IX

DISCUSSION

Saccharomycus fragilis may be grown on acid or sweet whey in a deep tank, aerated fermentor in a continuous manner on a commercial scale. The fermentation has many advantages. By operating at a low pH and with a large seed size and high cell count, contamination is no problem, and therefore, sterile or special aseptic equipment or techniques are not necessary. The aeration requirements are not excessive, (0.8 to 1.2 volume air per volume of medium) nor is there any problem with foam control. Temperature control, despite the rapid growth rate, is maintained with a low level of cooling water or by the addition of cooled medium in continuous operation. The medium is simple in composition, and at the concentrations used, the carbohydrate substrate (lactose) is completely soluble. The absence of any potentially toxic substances in the medium simplifies harvesting. The production of a whole fermented whey mass (Yeast Fermentation Solubles) eliminates additional processing of waste streams and increases the yield of the fermentation. As a result of the evaporation of the whole fermented mass prior to drying, condensate water is obtained that can be used to dilute incoming condensed whey and thereby operate a completely closed-loop system with no effluents.

Food grade yeast may be produced by harvesting the yeast by centrifugation. The supernatant streams (except the final washings) from this process may be used in certain animal feed fractions. The protein quality of the finished products is good, although slightly low in the sulfur containing amino acids, as is true for most single cell proteins. Rat feeding tests show no toxicity and feeding experiments with other animals show uses in other feed rations, especially those for cattle.

By varying the conditions of the fermentation, increased amounts of ethyl alcohol can be produced and recovered but at the expense of cell yield. However, as one expert has recently stated, "Energy considerations could also affect

the kind of SCP process. Aeration costs could be important if energy costs continue to rise. Hence, an anaerobic fermentation process, in which both alcohol and SCP feed are produced, could be the process of choice".[12]

The cost of production is dependent primarily on two factors -- the cost of whey and the capital investment. Efficiency demands a plant that is highly automated and instrument controlled and of a size to have an annual capacity of at least 5,000 - 10,000 tons of finished product. This would represent a raw material requirements of the equivalent of 200 to 500 million pounds of raw whey. Therefore the location of such a facility must be near a large cheese producing area. Such an area would have an excess of whey at little or no cost. The capital investment is large, but must be made to allow the product to compete in the market place. The vast majority of the material from such a plant must be sold as animal feed because at the present time human food uses for yeast is not of sufficient volume. Most of such feed products would be used in cattle feeds (either in concentrated liquid or dried form) because of the proximity of large numbers of these animals in this dairy (cheese producing) area.

The present and future shortage of protein has been reported extensively, and many investigators feel one potential solution is the production of single cell protein.[12] Agricultural and industrial waste materials may be used as substrates for such production thereby decreasing the immense disposal problems at present.[13,14] Whey is a clean, wholesome, food-grade substance, in excess supply and a potential environmental pollutant. By the process described here, it can be converted to a useful and needed high protein material, the demand for which is now present and should increase in the future.

SECTION X

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SECTION XI

GLOSSARY

Acid Whey--The product remaining after removal of casein and fat from cream in the process of making cream cheese, or from skim milk in the process of making cottage cheese.

Amber BYF 100--Autolyzed yeast fraction: Spray-dried yeast supernatant.

A.N.R.C. casein--A standardized casein product adopted for use by the Animal Nutrition Research Council for the Official Association of Analytical Chemists rat PER assays.

BOD--Five Day--Biological oxygen demand: Procedure performed in accordance with methods for the Examination of Water and Wastewater, 13th Ed., 1971, pp. 489-495. Expressed as milligrams per liter (mg/l) or parts per million (ppm).

Closed-loop system--Process of fermentation of whey producing no effluents.

N.U.R.L. Y-1109--Northern Utilization Research Laboratory, Strain Y-1109, Saccharomyces fragilis.

Nutrex--Food grade yeast obtained by harvesting and washing the cells by centrifugation of the fermented whey mass, followed by evaporation and drying.

YFS--Yeast Fermentation Solubles: Feed grade material obtained by the evaporation and drying the whole fermented whey mass.

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